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Decay and conservation of stone masonry

The durability of a stone is influenced mainly by its internal structure, though the nature of the cementing material that binds together the particles of sedimentary rocks, limestones and sandstones, also affects their performance. The most common cause of decay of stone in the UK is the crystallisation of salts within the pores; frost damage and other forms of attack also occur.

The mechanism of various forms of decay is discussed briefly in this digest, together with some methods of maintenance, stain removal, preservation and restoration.

Types of stone

Natural building stones may be obtained from igneous, sedimentary or metamorphic rocks. Igneous rock was formed by the cooling and solidification of molten material known as magma. The igneous stone that is most commonly used for building in Britain is granite; this is, technically, a coarse-grained, crystalline rock with more than 66 per cent silica in its chemical composition. In mineral composition, granites consist mainly of quartz, mica and felspars. Their porosity is usually very low and this, together with their mineral composition, accounts for their high resistance to weathering. In the building industry, the term granite is also applied to igneous rocks containing lower proportions of silica and sometimes to very hard rocks of quite different composition.

Sedimentary rocks provide the main British building stones, ie the limestones and sandstones. The original deposits from which they were formed consisted of loose, uncemented particles produced, for example, by the weathering of earlier rock, by accumulation of animal skeletons or by chemical deposition in lakes or seas. In the course of time, the sediments became cemented together to form porous, coherent masses. Although the nature of the cementing material has a strong bearing on the durability of some types, the internal structure of the stone is generally of greater importance. Limestones consist mainly of calcium carbonate; sandstones of quartz.

Metamorphic rocks were produced from sedimentary deposits by the action of heat and pressure within the earth's crust. Slate and marble are the only metamorphic stones that are commonly used for building in Britain. Slates were formed from clay deposits and marbles were formed by the crystallisation of limestones. There are only two true marbles in the British Isles, but some dense limestones will take a polish and, in the building industry, these are often referred to as marbles.

Causes of decay

Crystallisation of salts When salts crystallise within the pores of a stone, stresses may be generated that are sufficiently large to cause local fragmentation of the stone. This process is the major cause of stone decay in the British Isles. The salts may get into the stone in a number of ways, one of the more important being the ultimate production of calcium sulphate by the reaction of limestones with sulphur dioxide dissolved in rainwater. This can lead to two types of decay. In the features of a limestone building that are frequently wetted by rain, the repeated crystallisation of the calcium sulphate dislodges particles of stone which are subsequently washed off, together with the calcium sulphate, during very heavy rainfall. The surface of the stone therefore erodes gradually. In more sheltered parts, the calcium sulphate remains in position to form a hard and often dirty skin. With certain types of stone, this skin eventually blisters to reveal an underlying layer of crumbling debris.

The calcium sulphate that is washed out of limestones may cause crystallisation damage to other building materials that can absorb the contaminated rainwashings. Damage may also be caused by washings containing magnesium sulphate, formed by reaction of sulphur dioxide with magnesian limestones. For this reason, limestone should not be used in association with sandstone or brickwork in such a way that sulphates from the limestone may be picked up by these materials.

Other common sources of salts include groundwater, sea spray and unsuitable cleaning materials. Crystallisation damage caused by freely soluble salts such as sodium chloride, sodium sulphate or sodium hydroxide normally consists of a powdering and crumbling of the entire surface of the contaminated stones. When magnesian limestone is attacked by magnesium sulphate, deep cavities may be formed.

Some stones are virtually immune to crystallisation damage whereas others are liable to quite rapid decay; resistance is strongly dependent on the internal structure of the stone and decreases as the proportion of fine pores increases.

In this country, the mechanical removal of stone by wind-borne particles occurs only in exceptional circumstances, if at all, and most instances of decay that are attributed to wind erosion are probably due to crystallisation of salts. Any increase in the rate of decay in areas that are severely exposed to wind is usually due to the increased rate of evaporation which leads to an accumulation of salts and a higher frequency of crystallisation cycles.

Chemical attack Although chemical attack on stone can lead to the formation of salts, and thus contribute to crystallisation damage, chemical attack on its own is a major cause of decay only in special instances. One such, is the decay of calcareous sandstones, which consist of grains of silica bound solely by calcium carbonate. Sulphur dioxide and carbon dioxide dissolved in rainwater react with the calcium carbonate and the loss of a very small amount of carbonate results in the loss of a large number of silica grains.

Contour scaling Air pollution of a different kind is believed to be responsible for the 'contour scaling' of sandstones. A surface crust, following the contours of the surface rather than the bedding planes of the stone, breaks away at a depth of 5–20 mm. The crust is always found to have its pores blocked with calcium sulphate, even when the stone contains no calcium carbonate. This is believed to be the result of direct pollution with calcium sulphate, the fracture being caused by shear stresses arising from differences in the moisture movement or in the thermal expansion of the choked skin and the underlying stone.

Frost Frost damage occurs only in those features of a building that are frequently frozen whilst very wet and, in the British Isles, rarely occurs between damp-proof course and eaves. Frost may provide the 'last straw' that dislodges pieces of stone that have already been loosened by some other means, but this is readily distinguished from the spectacular cracking that occurs when frost is the sole cause of the damage. As with salt crystallisation damage, the susceptibility of a stone to frost damage is governed by its pore structure. This is partly because the pore structure governs the natural degree of saturation and partly because it governs the magnitude of the stresses that can be generated upon freezing. Most sandstones are immune to frost damage in this country.

Organic growths There is no evidence that bacteria or other micro-organisms play more than a small part in most instances of stone decay, but higher organisms such as lichens and plants can contribute to decay in some circumstances. For example, the acidic metabolic products of lichens can etch limestones, mosses can cause damage by forming reservoirs and the aerial roots of ivy can dislodge mortar from joints. However, the effects of lichens and algae are rarely serious and their presence is usually considered to enhance the appearance of stonework.

Other factors contributing to decay Sedimentary rocks have a natural bed and blocks of stone should usually be laid so that the bed is normal to the load. Face bedding, in which the bed lies parallel to the face of the wall, can lead to an increased rate of decay although it is not actually a cause of decay. The bedding planes constitute planes of weakness and the stone is more susceptible to crystallisation damage and other types of decay if the bedding layers are not restrained by the surrounding stonework.

A dense pointing mortar can also cause increased crystallisation damage by restricting the movement of water through it so that little evaporation can take place at the joints. Moisture in the wall must then evaporate from the stone itself and any salts will accumulate in the stone. Increased crystallisation damage will therefore occur. Since it is normally cheaper to repoint than to replace decayed stone, it is advisable to use a slightly permeable mortar which will deteriorate in preference to the stone. Suitable mixes are considered below.

The corrosion of steel or cast iron fixings can cause spalling of stonework. Dowels and fixings should, therefore, be made of non-ferrous metal or stainless steel as recommended in CP 121:Part 2.[1]

Conservation techniques

Cleaning The cleaning of exterior stonework is the subject of Digest 113.[2] Although unsuitable cleaning techniques or unskilled execution may damage stonework, there is no evidence that proper cleaning is harmful. On the contrary, by removing some of the soluble salts which cause decay it may prolong the life of the stone.

Stain removal Stains may be removed either by extracting the staining material with a suitable solvent, or by bleaching. In either case, it may be beneficial to apply the treatment as a poultice in an inert powder such as whiting or talc. The poultice

serves to absorb the staining material or to prolong contact of the bleach with the stone. It will usually be necessary to experiment on an inconspicuous area until an effective treatment is found. More than one application might be needed.

Oil stains may be removed by using solvents such as carbon tetrachloride, dichloromethane, white spirit or proprietary dry cleaning agents. Precautions against fire or inhalation should be taken as necessary.

Copper stains can sometimes be removed by treatment with ammonia solution. Several applications may be needed and the stains are liable to reappear. The stone should be wetted with water before the ammonia is applied and should be washed down thoroughly afterwards.

Iron stains on granite or sandstone may be removed by the application of orthophosphoric acid. This cannot be used, however, on limestones, marbles or calcareous sandstones, which would be attacked by the acid, but it may be possible to bleach the stains on these stones with a solution of sodium hydrosulphite. However, it should be emphasised that this treatment may leave salts in the stone that could subsequently cause severe crystallisation damage. It is, therefore, essential to saturate the stone with water before applying the hydrosulphite solution, and to wash down thoroughly afterwards.

Stains caused by organic materials can sometimes be bleached with a solution of hydrogen peroxide. This is preferable to household bleach for this purpose as it does not leave any harmful residue in the stone.

The removal of graffiti written in paint or with a felt-tipped pen can be particularly difficult. Solvent systems may be successful, particularly when combined with the use of a high-pressure water jet or poulticing, but there is a considerable risk that the paint or ink will be absorbed more deeply into a porous stone. Mechanical cleaning is probably more reliable. Both techniques are liable to leave a conspicuous clean patch, but this can sometimes be toned down by rubbing in a fine masonry dust of the appropriate colour.

Organic growths Removal of biological growths, lichens, moulds and similar, is discussed in Digest 139.[4] The following procedure has been found to be particularly effective for removing and inhibiting growths on exterior masonry:

apply a 1 per cent aqueous solution of a quaternary ammonium compound, preferably during the spring or autumn growing season. Moss and lichen should be saturated with the solution;

leave for two weeks;

remove dead growth with a stiff nylon brush and clean running water. A high-pressure water jet may be used where practicable;

after a drying period, apply an inhibitory treatment of tributyl tin oxide and a quaternary ammonium compound.

Stone preservation

Removal of soluble salts

The repeated crystallisation of salts is the most common cause of stone decay in the UK and the removal of these salts is one of several approaches to preservation. Washing with water may remove some of the salts but a proportion will be driven into the stone only to reappear at the surface as the stone dries out. A more thorough technique involves wetting the stone thoroughly and then applying a poultice of wet powdered clay. Attapulgus has been found to be more suitable for this purpose than sepiolite. As the stone subsequently dries, the salts are drawn into the poultice which is eventually removed. The operation is lengthy and may need to be repeated several times; it is only worth while if the source of the salts can be eliminated and this should always be done if possible.

Colourless preservative treatments

Water-repellent surface treatments are discussed in Digest 125.[3] Since water is involved in almost every type of stone decay, such treatments might appear to be promising preservatives. However, neither they nor any other colourless shallow treatments have been found to have any long-term preservative effect in most circumstances.[5] On the contrary, they may even accelerate decay. There are two main reasons for this. First, water will invariably get behind the treated layer, either by passing through it in the vapour phase or by absorption of rain or groundwater at some unprotected point. The water evaporates from behind the treated layer and any salts in solution crystallise there. This may lead to spalling of the treated surface. Secondly, the thermal and moisture movements of the thin surface layer may be sufficiently different from those of the underlying stone to generate shear stresses that eventually cause failure.

A more promising approach to preservation is the deep impregnation of stonework with suitable resins. A deeply penetrating treatment would secure the decaying surface to the underlying sound stone and would overcome the problems encountered with shallow treatments. In addition to consolidating the stone, a treatment of this type might be expected to prevent further crystallisation damage, either by making the salts inaccessible to water or by modifying the properties of the stone to make it more resistant. The minimum thickness of the treated layer is not known and will vary from one type of stone to another, but a thickness of at least 25 mm will probably be required in most circumstances.

The Station is currently assessing the effectiveness of various deep impregnation treatments and it is not

yet possible to make any specific recommendations. The most promising materials fall into three main categories:

alkoxysilanes These materials react with water to give a silicone polymer, curing being dependent on the loss of alcohol by evaporation.

solutions of epoxy resins Common epoxy resins are rather viscous and must, therefore, be dissolved in solvent in order to achieve penetration.

With both of these classes of materials, solvents must evaporate from the surface of the stonework. This means that it is not possible to achieve complete pore filling and the treated stone remains permeable to water vapour.

waxes These are discussed in Digest 125. The stonework must be heated in order to melt the wax and in many circumstances this will not be practicable.

Deep impregnation treatments naturally require large quantities of material and the costs are such that it may be unrealistic to contemplate the preservation of anything other than valuable detail. In many circumstances it will therefore be necessary to use one of the traditional maintenance and restoration techniques.

Maintenance and restoration

The work to be undertaken will often be governed by financial considerations. The following procedures are listed in order of increasing cost.

1 Knock off any loose stone and repoint where necessary. Suitable pointing mixes are 1:2:9 cement:lime:sand (by volume) and 1:8 cement: sand with a vinsol resin plasticiser.

2 Redress the stonework until a sound face is exposed and repoint. In many cases this may be all that is necessary to give satisfactory service for a good number of years. However, it may not be practicable where there are elaborate architectural details.

3 Redress until a sound face is exposed and then restore the stonework to its original line by setting in a facing of artificial or natural stone, or by building up with a suitable mortar. The selection of durable stone will be the subject of a future digest; the principles to be observed when building up with mortar are as follows:

The exact composition of the mix should be determined by experiment, to match the colour of the surrounding stonework. Suitable mixes may be based on Portland cement, using graded sand or crushed stone aggregate, or a mixture of these. Lime may be added to increase workability, but this may also be achieved by the addition of an air-entraining agent. Accelerators, such as calcium chloride, should not be used. Any pigments that are added should comply with BS 1014 and should not exceed 10 per cent by weight of the cement. The mix should be as dry as is compatible with the retention of workability. A number of organic binders for use with crushed stone or sand have been proposed, but the Station has relatively little experience of their durability.

The thickness of the repair should normally not be less than about 20 mm at any point, although this may not be practicable in all circumstances, particularly on carved work; feather-edging should always be avoided. Non-ferrous wire or dowels should be used where necessary to improve the key. Each block should be built up individually, the joints between adjacent blocks being left open and pointed at a later date. The alternative of building up large areas and striking in artificial joints should be avoided because of the risk of crazing. Large repairs should be built up gradually, step by step, each layer being allowed to set before proceeding with the next. Repairs should not be finished with a steel trowel but with a board or rough wooden float. Laitance may be removed by applying a wet brush before the repair has set or by brushing the freshly set mortar with a stiff dry brush. To obtain the best results, the repair may be built up until it stands proud of the surrounding stonework. It is then tooled back to the required level after setting.

References and further reading

1 CP 121: *Walling:* Part 2: *Stone masonry* British Standards Institution, London

2 BRE Digest 113 *Cleaning external surfaces of buildings*

3 BRE Digest 125 *Colourless treatments for masonry*

4 BRE Digest 139 *Control of lichens, moulds and similar growths*

5 B L Clarke and J Ashurst *Stone preservation experiments* BRE: 1972 (£1·25)

6 R J Schaffer *The weathering of natural building stones* BRE: 1932, reprinted 1972 (£2)

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